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Effects of Climate Change on Rice Yield in Northern Areas of Iran: Humidity as a Large Variability of Climate

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Abstract: Climate has a significant effect on social and economic activities, and currently is a major problem, especially in agricultural yields. This study used two types of climatic and agricultural data. To simulate the climate for the next 30 years (2021-2050) from daily temperature and precipitation data for the base period 1986-2015, Reanalysis Atmospheric Data (NCEP) as observational predictors data and CanESM2 Atmospheric General Circulation Model data with two scenarios RCP 2.6 and RCP 8.5 were used as large-scale predictors. The data is related to the Rasht Rice Research Center field experiments. The results abstained from simulations showed that in future climate conditions, the average temperature would be 0.7 to 0.9°C, and precipitation would be 20 to 70 mm in the study area based on both emission scenarios compared to the base period (1986-2015) increases. The effect of climate change on the rice yield on the planting date of June 5, especially in the eastern parts of the region, is unfavourable in the future. At the regional level, in all planting dates, the length of the rice growth period in the future period (2021-2050) will decrease by 2 to 4 days compared to the base period. The planting date treatment of 5 May with a density level of 50 plants per square meter, a nitrogen fertiliser level of 195 kg per hectare with an intermittent irrigation regime (8-day cycle) is the most suitable adaptation strategy to reduce the negative effects of climate change and increase rice yield in the entire surface of the coastal area in the Caspian Sea.

Keywords: Climate change; Exponential microscale; Cultivation pattern; Rice; APSIM model.

Introduction

In recent decades, climate change has been an important issue, especially in arid and semi-arid regions around the world. Iran is one of these arid regions, which, according to the future climate scenarios, is predicted to have an average temperature increase of 4.0°C from 0 to 3.5°C (Fakheran et al., 2018; Ziaee et al., 2021). The agricultural sector is most sensitive and vulnerable to climate change (Zhou et al., 2019). Therefore, assessing the effects of global climate change and ensuring future food security under changing climate conditions are important issues of the 21st century (Liu et al., 2019; Jing et al., 2021). Iran, as a water-scarce country, is highly sensitive to climate change (Karami et al., 2019).

Rice is one of the main crops required to feed a large part of the world's population (Arouna et al., 2021). According to the FAO report (2016-2017), the average

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world rice production is estimated at 108 × 5 tonnes per year, and due to population growth, the production requirement is expected to increase to 2 × 109 tonnes by 2030 (Mishra et al., 2021). Rice requires a large amount of water during the growing season, and water shortages caused by drought easily reduce rice production (Wang et al., 2021). Research related to the effect of climate change on rice production is diverse and includes different approaches and methods. So, in this study, the effects of drought on rice production in different short-term (2019-2039), medium-term (2069-2040) and long-term (2070-2099) periods were analysed using data from Representative Concentration Pathway (RCP) scenarios and the Environmental Policy Integrated Climate Model (EPIC). Its results showed that the average expected decline rate of global rice yield might reach 13.1% in the future (Wang et al., 2021). DSSAT model, on the effect of climate change on the yield of wheat and rice in the Kanga basin investigated by Mishra et al. (2013) showed that the yield of wheat and rice will decrease from 2011 to 2040. The effect of climate change on rice yield in the northeastern plains of China investigated in the 2030s, 2060s, and 2090s showed that regardless of CO_2 effects, rice yield under the RCP scenario 4.5 increase and under the RCP 8.5 scenario and will increase by 1% in the 2030s and decrease by 2.3% and 10.7% in the 2060s and 2090s, respectively (Zhou et al., 2019). In another study, the results showed a decrease in the average rice yield in the southeast plains of China by 3.5 and 9.4 percent for the RCP 4.5 scenario and 10.5 and 47.9 percent for the RCP 8.5 scenario in the 2050s and 2080s, respectively (Yang et al., 2021; Arunrat et al., 2022). In India, the impact of climate change on rice yield under RCP scenarios showed that Indian rice yield increases by 1.5% under RCP scenarios (Surendran et al., 2021).

The impact of climate change on the yield of rice in each region depends on the adaptation of strategies such as changes in management related to irrigation, soil, planting date, activities, and technologies used in crop cultivation can significantly reduce the effects of climate change in any region (Mall et al., 2017, Sherestha et al., 2017). Chun et al. (2016) in assessing the effect of climate change on rice yield in five countries of Cambodia, Myanmar, Laos, Thailand, and Vietnam in Southeast Asia, found that the use of adaptive strategies such as irrigation, doubling of nitrogen fertiliser and appropriate planting date can significantly reduce the negative effects of climate change on rice yield. Ojo and Baiyegunhi (2020) and Sherestha et al. (2017) evaluated potential adaptation measures to improve rice yield.

Rice cultivation is common in the northern regions of Iran, with humid and moderate climate and high annual rainfall. In Iran, changes in climatic components such as precipitation, temperature, frequency, and intensity of extreme phenomena such as drought, floods, and storms can affect the growth and production of agricultural crops in the country's northern regions in different ways. Therefore, it is necessary to know the nature of the effect of climate change on rice yield, which is discussed in this study.

Data and Method

Study Area

Iran is located in Southwest Asia, between latitudes 25º to 40ºN and longitudes 44º to 63º E. The research area is the southern coast of the Caspian Sea, which is Iran's main rice-growing area and is located in the north of the country. Rice cultivation is more common than other grains due to the humid and moderate climate with high annual precipitation and heavy and alluvial soils. The region, with an area of 65,912 square kilometers, is located between the Caspian Sea and Alborz Mountain range. The sum of local and regional factors, such as proximity to the sea, vegetation cover, and the dominance of different air conditions, cause the accumulation of moisture and significant precipitation in this region. Due to the influence of the Sea, high humidity, fluctuation of the daily and seasonal temperature is low in the plains and coastal regions.

Input Data and Simulation of Future Climates

This research to simulate the changes in climate variables in the study area during the future period of 2021-2050, compared to the base period of 1986-2015, from the daily data of climate variables of seven synoptic weather stations (Astara, Rasht, Bandar Anzali, Ramsar, Qarakhil, Nowshahr, and Babolesar) (Figure 1) and for the base period 1986-2015, atmospheric reanalysis data [NCEP] as predictor data and CanESM2 atmospheric general circulation model data under two scenarios, RCP 2.6 and RCP 8.5. were used as a large-scale predictor. Since NCEP data are available in the fifth report of the CanESM2 model up to 2005, observational forecast data were obtained from the NCEP–NCAR database up to 2015 on a daily time scale. The CanESM2 large-scale predictor data were obtained from the Canadian Center for Climate Analysis and Modeling website at: climate-scenarios.canada.ca/? page-pred-canesm2. The CanESM2 model is an upgraded version of the

Figure 1: Location of the study area and meteorological stations used in the research.

general circulation model. Downscaling the CanESM2 atmospheric general circulation model data was done using SDSM4.2 software. To ensure that the model can simulate data outside the calibration time range (1986-2000), the daily data of climate variables for the statistical period of 2001-2015 were simulated, and by comparing the observed and simulated data, the efficiency of the model was checked. At this stage, to check the efficiency of the model, the non-parametric Wilcoxon test and the error measurement profiles of the mass coefficient of error, the root mean square error, and the coefficient of agreement were used.

Input Data and Agricultural Model Simulation

The rice module in the APSIM process model (APSIM-Oryza) was used to simulate the growth and yield of rice. The rice module in APSIM (APSIM-Oryza) simulates the growth and production of rice under conditions of potential and limited water and nitrogen fertiliser. APSIM-Oryza is related to other APSIM components such as soil water, irrigation, and fertilization (Liu et al., 2019). The APSIM model's required inputs for simulating daily growth include weather data (temperature, precipitation, radiation intensity), soil, genetic coefficients, and management information. Considering that radiation intensity is one of the inputs of the APSIM model and this variable is not recorded in the Meteorological Organization, it was estimated using the sunshine hours variable. In order to calculate the radiation intensity, first using the PhotoPeriod Calculator program written by the researchers of the Agricultural Production Systems Research Unit (APSRU) in Australia, the daily high atmospheric radiation intensity in megajoules per square meter per day ($M/m^2/day$) in each obtained from selected stations. Then, the Angstrom-Prescott relation (Relation 1) was used to convert the high atmospheric radiation intensity (R_g) to the amount of radiation on the earth's surface.

$$\text{Relationship } 1 \frac{R_S}{R_O} = a + b\left(\frac{n}{N}\right)$$

where R_O is the total radiation received from the sun on a horizontal surface above the earth's atmosphere, R_S is the total radiation received from the sun on a horizontal surface on the earth's surface, n is the length of sunny hours, and N is the length of the day (Shariatmadari and Kamali, 2018). Also, a and b are specific empirical coefficients specified in advance for each region. Coefficients a and b are 0.40 and 0.23, respectively, for different areas of the southern shores of the Caspian Sea.

The agricultural data used in this research is related to the rice field experiments of the Rasht Rice Research Center, which is located at the latitude of 37°12'N and a longitude of 49°38'E, and a height of 7 meters ASL. This experiment was carried out in the years 2010 and 2011 on two planting dates, June 5 and May 5, respectively, with a density of 25 bunches per square meter of land, nitrogen treatment of 130 kg divided in two times, and two treatments of flooding and irrigation with 8-day intervals. The rice cultivar was Hashemi, which is the dominant cultivar in the study area. First, the genetic coefficients of the Hashemi variety were determined, and the model was validated. In the evaluation and validation stage of the model, the observed values of flowering, ripening, and performance were compared with those simulated by the model. To evaluate and validate the model and to check its accuracy of the model, the statistical indicators of mass coefficient of error and root mean square percentage of error (RMSPE), as well as coefficient of agreement (d-Index), were used. After the calibration and validation of the model, rice yield was simulated in the base and future periods, and the effects of management scenarios on rice yield were investigated. Rice stimulation treatments and experiments were also conducted under potential and stress-free conditions. Treatments and long-term experiments of rice simulation from one variety, including the Hashemi variety, two planting dates including May 5 (T1) and 5 Jun (T2), three levels of nitrogen fertiliser in the form of 65 kg/ha (F1), 130 kg/ha (F2)) and 195 kg/ha (F3), three density levels including 25 seeds per square meter (D1), 37 seeds per square meter (D2) and 50 seeds per square meter (D3), two irrigation regimes including flood irrigation (W1) and intermittent irrigation with an 8-day cycle

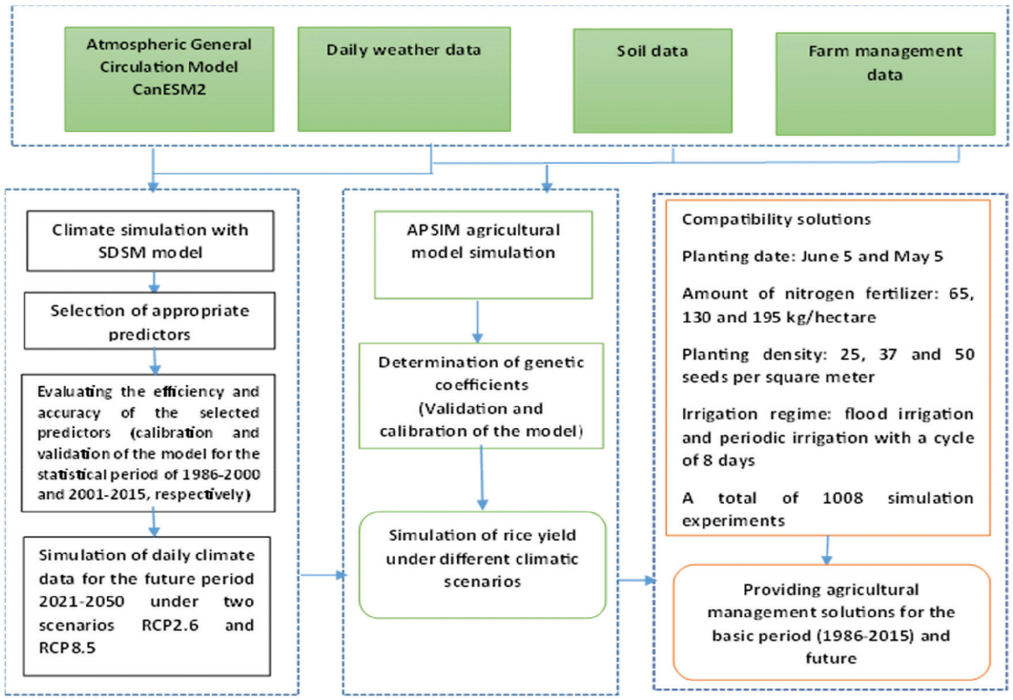

Figure 2: Workflow of the research.

(W2), a base period and a future period (under two scenarios) were formed in 30 years, which included a total of 1008 simulation experiments. Figure 2 shows the methodology used in this research.

Results

Simulating the Future Climate

The calibration and validation results showed the relatively appropriate efficiency of the SDSM model in simulating precipitation, temperature, and sunshine hours in the study area. The results of all the statistical parameters of error measurement confirmed the model's effectiveness. Based on the Wilcoxon test, it was found that in all the studied stations, the *P*-value is 0.05, and indicating no significant difference between the average observed and simulated rainfall data in seasonal and annual time scales.

Temperature Variable Simulation Results

The comparison of the average temperature in the base and future period (under different emission scenarios) showed that the average temperature in the future period of 2021-2050 under RCP 2.6 and RCP 8.5 emission scenarios in Astara station is 0.75 and 0.82ºC; Babolsar station is 0.87 and 0.91ºC; Bandar Anzali station is 0.77 and 0.83ºC; Ramsar station is 0.74 and 0.82ºC; Rasht station is 0.82 and 0.84ºC respectively; Gharakhil station is 0.88 and 0.92ºC; and Nowshahr station are 0.78 and 0.86ºC respectively. Therefore, it is expected that based on both emission scenarios under investigation, the average temperature in the future period (2021-2050) will be, on average, 0.7 to 0.9ºC compared to the base period (1986-2015) in increasing the level of the studied area.

Simulation Results of Precipitation Variable

The average total precipitation in the future period 2021-2050 under RCP 2.6 and RCP 8.5 emission scenarios in Astara station is 63 and 62 mm in station 52 and 52 mm in Babolsar, 72 and 77 mm in Bandar Anzali station, 45 and 40 mm in Ramsar station, 70 and 71 mm in Rasht station, 42 and 71 mm in Ghaemshahr station, respectively, 22 mm, and in the Nowshahr station, it increases by 62 and 60 mm, respectively, compared to the base period. Therefore, is expected that based on both the investigated emission scenarios, the average rainfall in the future period (2021-2050) will increase by an average of 20 to 75 mm compared to the base period (1986-2015) in the study area.

APSIM Agricultural Model Simulation

Calibration of APSIM-Oryza Model

Different cultivars of agricultural plants are different in terms of physiological and morphological characteristics, so the varietal difference between different cultivars must be considered in plant simulation models to make an acceptable prediction. Therefore, to obtain more accurate results, it is necessary to determine the genetic coefficients first. Table 1 shows the results related to the genetic coefficients of the Hashemi rice variety.

Table 1: Genetic coefficients related to rice (Hashemi variety) in the APSIM-Oryza model

Parameter	*Value*	*Unit*
Development rate in the juvenile phase	0.001572	˚C day
Development rate in photoperiod-sensitive phase	0.000920	˚C day
Development rate in panicle development	0.000795	˚C day
Development rate in the reproductive phase	0.002512	˚C day
Maximum optimum photoperiod	11.50	h
Photoperiod sensitivity	0.0	h-1
Spikelet growth factor	64900	no./kg
Maximum individual grain weight	0.0000249	kg/grain

Validation of the APSIM-Oryza Model

RMSPE values as an index of model efficiency are less than 10% in all cases. Agreement index is close to one in all cases. Therefore, the obtained results indicate that the model has well simulated the stages of flowering, ripening, and yield, so the parameters estimated for the Hashemi cultivar are accurate and confirmed (Table 2).

Length of Rice Growing Period

Figures 3 and 4 show the spatial distribution of the changes in the length of the rice growth period in the base and future periods (under the investigated emission scenarios) on the planting dates of May 5 and June 5. Given in Figures 3 and 4, the basic period (1986-2015), the length of flowering and physiological maturity was equal to 70 and 93 days, respectively. The results of both release scenarios showed that in all studied stations, the length of the day until flowering is reduced by an average of 2 to 3 days compared to the base period. Investigating the spatial distribution of the changes in the length of the rice growth period in both planting dates showed that in the study area, the length of the growth period in the future period will decrease by an average of 2 to 4 days compared to the base period. The reduction in the length of the rice growing season in the future period is related to the increase in temperature in the future period compared to the base period.

In the basic and future periods, the planting date of June 5 had a shorter growth period (days to flowering and days to maturity) than the planting date of May 5 (Figures 3 and 4). Because most of the final stages of the growth period are in the warm period of the growing season due to more temperature this increases the speed during the growth stages and ultimately shortens the growth period. In both the investigated planting dates, the shortest growth period was related to the eastern parts of the study area, especially the Babolsar station. In this station, the average length of the growth period on the planting date of May 5 was 92 days in the base period and 89 days in the future period, and on the

Table 2: Validation results of the APSIM-Oryza model

Experiment		*Yield (kg per hectare)*		*Days to maturity (days after planting)*	*Days to flowering (days after planting)*
		Intermittent irrigation treatment (8 days cycle)	*Flood treatment*		
2010-06-05	Observed	4388	4340	88	63
	Simulated	4071	4317	87	63
	RMSPE (%)	1	0.1	0.2	0
	d value	1	1	1	1
	CRM	0.07	0.01	0.01	0
2011-05-05	Observed	3534	4356	89	65
	Simulated	4980	4900	91	67
	RMSPE (%)	8	2	0.4	0.6
	d value	0.97	1	1	1
	CRM	-0.4	-0.1	-0.02	-0.03

planting date of June 5, it was an average of 86 days in the base period and 84 days in the future period. The higher average temperature in the base period (24.4°C) and the future (25.5°C) during the rice growing season significantly shortened the rice growing period in Babolsar station. The spatial distribution pattern of the rice growth period in the base and future periods showed that the growth period is longer towards the western parts of the study area. Astara station had the longest growing season among the studied stations in the base period, with an average of 92 days on the planting date of June 5 and 99 days on the planting date of May 5. In the future, the longest growth period was related to the Astara station on the May 5th planting date, and June 5th planting date was related to the Astara and Rasht stations.

Effect of Planting Date on Rice Yield

In all studied stations, the planting date significantly affects rice yield and the planting date of June 5 has the lowest yield in the base period and the future under different scenarios (Table 3 and Figure 5).

The zoning of rice yield in the base and future periods (based on both release scenarios) on the planting dates of May 5 and June 5 is shown in Figures 6 and 7. According to Table 4 and Figures 6 and 7, the results showed a decrease in rice grain yield in the future compared to the base period on the planting date of June 5 in the studied area. On this planting date, based on the results of the RCP 2.6 and RCP 8.5 release scenarios, the yield of rice grains in Astara, Babolsar, Bandar Anzali, Ramsar, Rasht, Ghaemshahr and Nowshahr

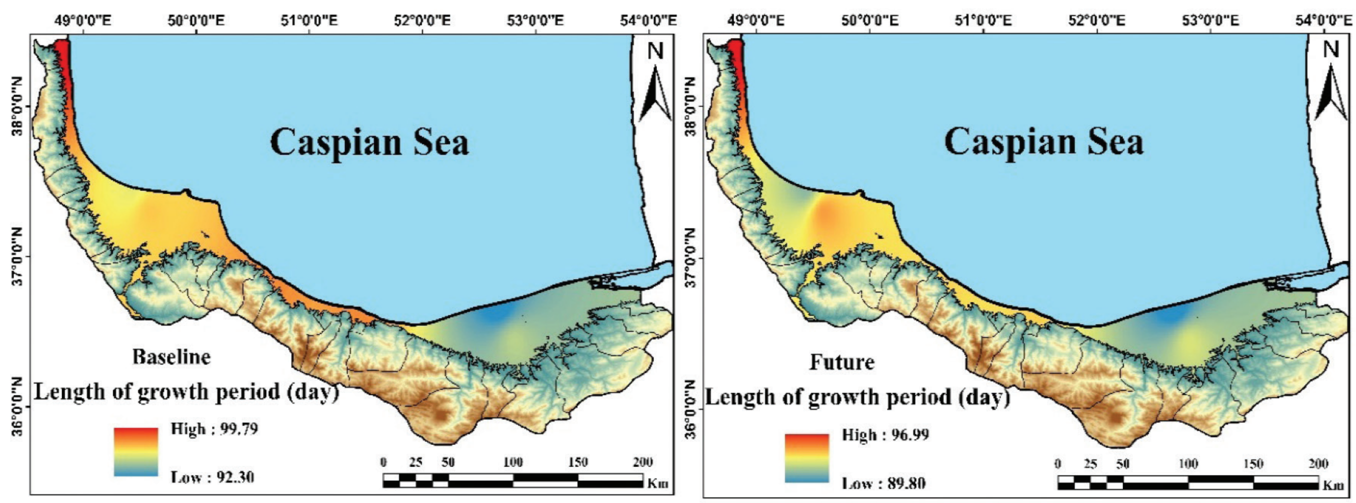

Figure 3: Length of the rice growing season in the base and future periods on the planting date of May 5 under different scenarios.

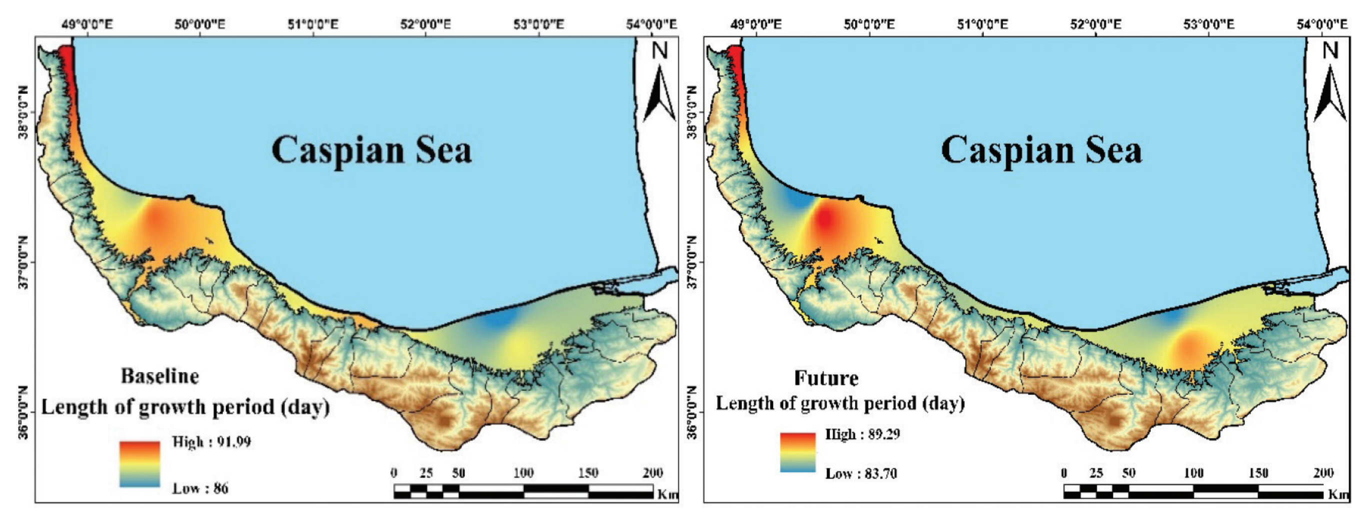

Figure 4: Length of the rice growing season in the base and future periods on the planting date of June 5 under different scenarios.

Table 3: Effect of planting date on rice yield

Station	*Parameter*	*Cultivation*	
		June 5	*May 5*
Astara	Basic period	5151.7**	6123**
	RCP 2.6	4972**	6034**
	RCP 8.5	4995**	6046**
Babolsar	Basic period	4331**	5581**
	RCP 2.6	4297**	5623**
	RCP 8.5	4283**	5612**
Bandar Anzali	Basic period	4536**	5534**
	RCP 2.6	4225**	5466**
	RCP 8.5	4262**	5494**
Ramsar	Basic period	4585**	5702**
	RCP 2.6	4388**	5629**
	RCP 8.5	4344**	5563**
Rasht	Basic period	4828**	5868**
	RCP 2.6	4765**	5953**
	RCP 8.5	4797**	5976**
Ghaemshahr	Basic period	4671**	5879**
	RCP 2.6	4589**	5881**
	RCP 8.5	4618**	5912**
Nowshahr	Basic period	4742**	5870**
	RCP 2.6	4506**	5755**
	RCP 8.5	4486**	5738**

stations is on average 168.2, 41,292.5, 219, 47, 67.5, and 246 kg per hectare, respectively, will decrease compared to the base period. Also, the results for the planting date of May 5 showed that the yield of rice in Babolsar, Rasht, and Ghaemshahr stations increased by 36.5, 96.5, and 17.5 kg per hectare, respectively, compared to the base period. In Astara and Bandar Anzali stations, Ramsar and Nowshahr, respectively, the yields are reduced by 83, 54, 106, and 123.5 kg per hectare compared to the base period. The growing period of rice in the study area is from early May to late September. During the growing season, rice needs 750 to 1500 mm and, on average, 1200 mm of water. The rice yield is higher in areas where the amount of rainfall is 700 to 2500 mm. The amount of rainfall in Astara, Babolsar, Bandar Anzali, Ramsar, Rasht, Qaimshahr, and Nowshahr stations during the rice growing season is 526, 230, 578, 404, 416, 241, and 422 mm, respectively. The lowest precipitation is received

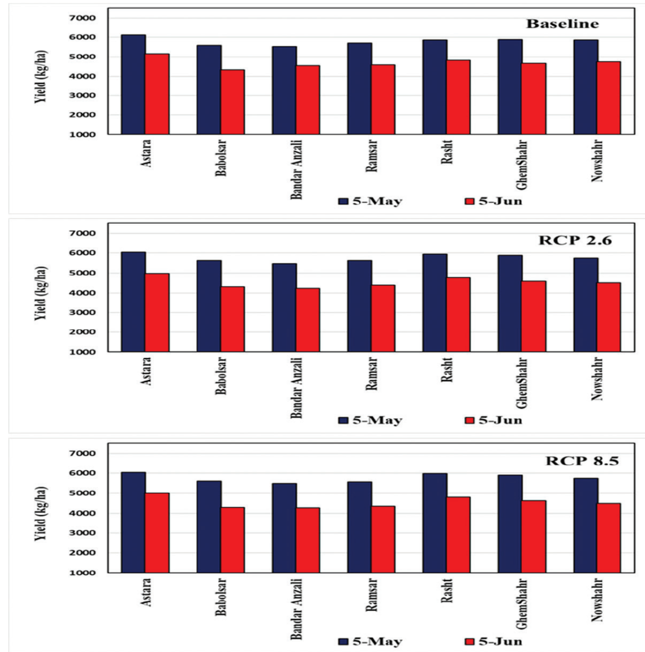

Figure 5: Effect of planting date on rice yield in different planting dates in the base and future periods.

in the spring season, and based on the results obtained, in most of the stations, the amount of precipitation during the months of the growing season, especially in the early stages of growth, such as April and May, is reduced compared to the base period. On average, 30 to 50 percent of rice water needs are provided by rainwater and the rest through irrigation management. Sefidroud River is the main source of irrigation water for paddy fields in Gilan province, which has decreased in recent years due to drought. The other factors, such as improper distribution of rainfall and weak management of irrigation water distribution, supply irrigation water is insufficient to supply water to paddy fields. Therefore, planting rice in the study area at the beginning of May is better to achieve economic yield.

Interaction Effect of Planting Date, Density, and Fertiliser on Rice Yield

Examining the results of variance analysis Table 5 showed that the interaction effect of planting date, density, and nitrogen fertilizer on rice yield in the studied area is significant at the 1% probability level which indicates the difference in the trend of changes in rice yield with density and nitrogen fertiliser in the dates. There were three cultivation treatments, including the planting date of May 5, with a density level of 50 plants per square meter and a nitrogen fertiliser level of 195 kg per hectare, and the planting date of May 5

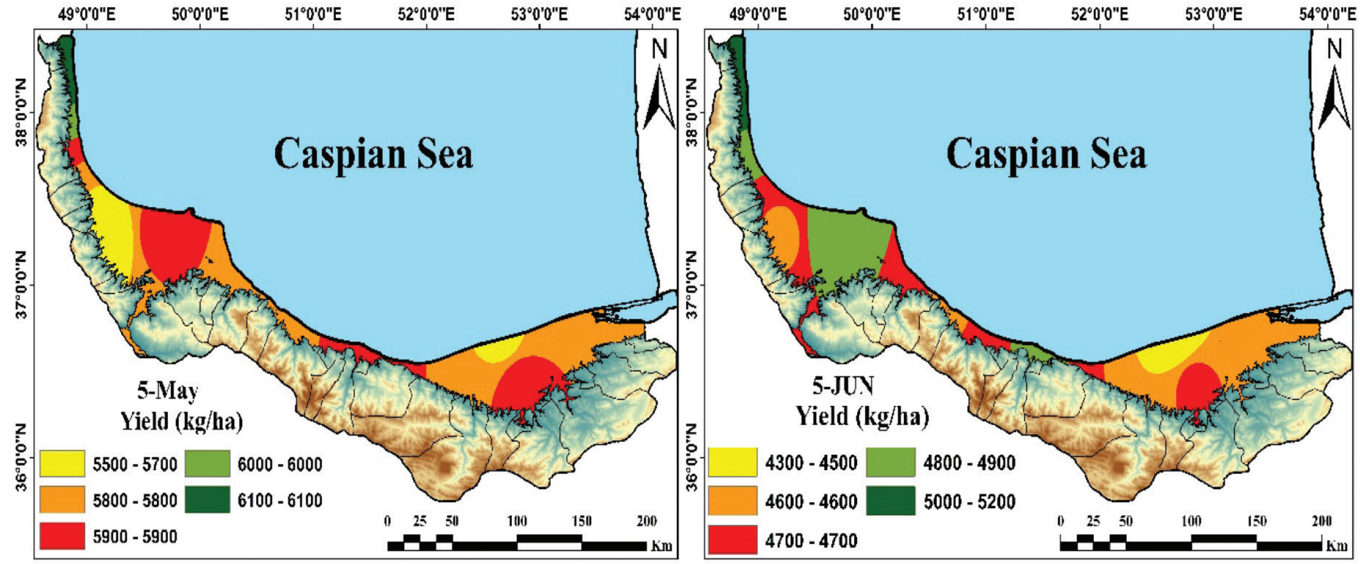

Figure 6: Rice yield in the study area in the baseline (1986-2015) in different planting dates.

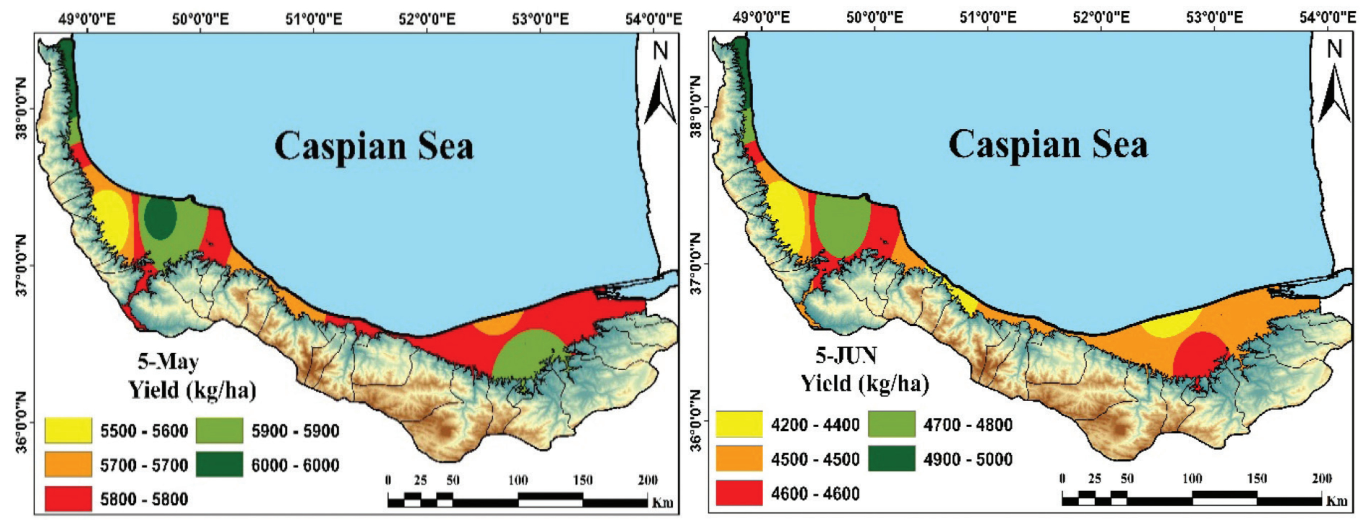

Figure 7: Rice yield in the study area in the future (2021-2050) in different planting dates.

Table 4: Rice yield changes compared to the base period under RCP 2.6 and RCP 8.5 emission (kg/ha + increase - decrease)

Planting date	*Scenario*	*Astara*	*Babolsar*	*Bandar Anzali*	*Ramsar*	*Rasht*	*Ghaemshar*	*Nowshahr*
5 May	RCP 2.6	89-	42+	68-	73-	85+	0+	115-
	RCP 8.5	77-	31+	40-	139-	108+	33+	132-
5 Jun	RCP 2.6	179-	34-	311-	197-	63-	82-	236-
	RCP 8.5	156-	48-	274-	241-	31-	53-	256-

Table 5: Variance analysis of the interaction effect of planting date, density, and fertiliser on rice yield in the base period and the future

Scenarios	*Astara*	*Babolsar*	*Bandar Anzali*	*Ramsar*	*Rasht*	*Ghaemshahr*	*Nowshahr*
Basic period	1158907.2**	1380292**	107949**	1255419.1**	1174320**	1395929.6**	1282201.4**
RCP 2.6	1234047.8**	1506882.5**	1321799.9**	1381980.4**	1336475.8**	1522168.5**	1398035.6**
RCP 8.5	1208135.2**	1514361.5**	1309993**	1347761.8**	1332389.2**	1531584.9**	13997642.5**

with a density level of 37 plants. In the square meter and nitrogen fertiliser level of 130 and the planting date of 5 May, the density level of 25 plants per square meter and 65 kg per hectare had the highest rice yield among the 18 cultivation treatments. In all the studied stations, the lowest rice yield was on 5 June, a density level of 25 plants per square meter, and the nitrogen fertiliser was 65 kg per hectare.

Mutual Effect of Planting Date, Density, Fertiliser, and Irrigation on Rice Yield

The investigation and comparison of 36 rice cultivation treatments in the base and future period showed that in all the studied treatment stations> the planting date was 5 May with a density of 50 plants per square meter, and the level of nitrogen fertiliser was 195 kg per hectare with the type of periodic irrigation regime (8-day cycle) had the highest yield. The highest performance in the future period in Astara, Nowshahr, Ramsar, and Ghaem Shahr stations (based on RCP 2.6 and RCP 8.5 scenarios), Rasht station (based on RCP 2.6 scenarios) and Babolsar station (based on RCP 8.5 scenarios) will be May 5, the density level was 50 plants per square meter, the nitrogen fertiliser as 195 kg per hectare, and the type of irrigation regime was flood irrigation. In Bandar Anzali stations (based on RCP 2.6 scenarios) and Rasht (based on RCP 8.5 scenarios), the planting date 5 May with a density level of 50 plants per square meter, and nitrogen fertiliser level is 130 kg per hectare with an intermittent irrigation regime (8-day cycle) and ranked second in terms of the average yield of rice. The lowest yield in the base and future period was related to the treatment of planting date 5 June with a density level of 25 plants per square meter and nitrogen fertiliser level of 65 kg per hectare with flood irrigation regime.

Discussion

The temperature simulation results for the future period of 2021-2050 indicated an increase in temperature on the southern shores of the Caspian Sea. Analysing the simulation results of precipitation data for the period 2021-2050 showed that the study area will not decrease in the future period of 2021-2050, it seems that in the studied area, the amount of precipitation during the future period of 2021-2050 will increase by an average of 20 to 70 mm compared to the base period (1986-2015). The investigation of the studies conducted in the field of simulation of precipitation in the provinces along the Caspian Sea showed an increase in precipitation during the future period in most of the stations, which include the research of Khorshiddoust et al. (2017), Dastranj et al. (2016) and Ahmadi et al. (2017).

In north Iran, planting operations start at the beginning of May. In this context, since choosing the right planting date optimises the efficiency of using effective environmental factors and increases yield, the yield of rice was investigated on two planting dates, May 5 and June 5. The results showed a decrease in rice grain yield in the future compared to the base period on the planting date of June 5 in the studied area. Occurrence of high temperatures, receiving less cumulative radiation, and low index of leaf surface by creating unfavourable environmental conditions, especially during the seed filling period, causes a decrease in yield. The occurrence of higher temperatures on this planting date increases the seed growth rate and reduces the filling period, which causes a decrease in seed weight. Also, the leaf area index is one of the main factors in evaluating the seed yield of agricultural plants. The length of the appropriate growing season, relatively higher leaf area index, receiving more cumulative radiation due to the length of the growing period, the adaptation of phenological stages, especially the flowering stages, and dealing with suitable and more favourable temperatures can be the reason for the superiority of the planting date of 5 May in the studied area.

In order to achieve a suitable and desirable yield, it is better to plant rice in the study area at the beginning of May. Late planting of rice crops adversely affects growth and final yield due to adverse environmental conditions. The results obtained in the field of optimal planting date are consistent with the findings of Kamkar et al. (2019), Darzi Naftchali and Karandish (2016) and Esfahani et al. (2018).

The results of investigating the effect of density at three levels of 25, 37, and 50 plants per square meter on rice yield showed a significant effect of density on rice yield. The highest yield was obtained in the density treatment of 50 plants per square meter. Proper density and balanced distribution of plants per unit area leads to better use of moisture, nutrients, and light and increases yield. Considering that the highest yield was achieved in the density treatment of 50 plants per square meter, it seems that in the climatic and environmental conditions of the study area, the environmental conditions and access of the rice plant to moisture, light, and soil nutrients are at least up to the density of 50 plants per square meter is not too restrictive. Esfahani et al. (2016), Kheyri et al. (2015), and Babazadeh et al. (2018) also achieved similar results in their research on the effect of compaction on rice yield. The results of variance analysis of fertiliser effect at three levels of 65, 130, and 195 kg/ha on rice yield showed that the effect of fertiliser on rice yield is not statistically significant in all studied stations. Even though the effect of fertiliser on rice yield was not statistically significant, the average comparison using Duncan's test showed that the highest grain yield was obtained at the fertiliser level of 195 kg/ha. Ashouri and Rudsari (2019) considered a fertiliser level of 80 kg per hectare for Rodsar City, and Nahvi et al. (2006) considered a nitrogen fertiliser level of 175 kg per hectare for Rasht City. A comparison of the flood irrigation method with the periodic irrigation method with eight days cycle showed that the periodic irrigation method with eight days cycle could save the amount of water consumed without causing a significant decrease in yield, which is consistent with the findings of Babazadeh et al. (2018). The results of the mutual effect of planting date, density, and fertiliser on rice yield showed that the interaction effect of planting date, density, and fertiliser on rice yield in the studied area is significant at the 1% probability level. In this context, researchers such as Moradpour et al. (2016) and Ashouri and Rudsari (2019) also pointed out the significant effect of planting date, density, and fertiliser on rice yield.

Conclusion

The effect of climate change on rice yield on the planting date of June 5 is negative in the entire study area. Meanwhile, the results for the planting date, i.e., May 5, showed that the rice yield in Babolsar, Rasht, and Ghaemshahr stations increased and decreased in Astara, Bandar Anzali, Ramsar, and Nowshahr stations as compared with the base period. In general, based on the obtained results, it can be said that the combined effects of temperature increase and decrease or uncertainty of the optimal amount of precipitation in spring and summer seasons, which coincide with the rice growth period, for rice yield, especially in the eastern parts of the study area in the future period are unfavourable. On the planting date of 5 May, the stages of growth and development of rice are in favourable environmental conditions, and they are less likely to deal with adverse environmental conditions. Therefore, it is better to start planting rice in the study area in early May.

Comparing the average yield of rice in two treatments of permanent flooding and intermittent irrigation with 8 days cycle showed that, on the planting date of 5 Jun, the yield of rice in intermittent irrigation treatment with 8 days cycle is more favourable than flooding treatment. On the planting date of 5 May in the stations of Astara, Bandar Anzali in the base period, Ramsar in the base period and RCP 2.6 and RCP 8.5 scenarios, Rasht in the base period, Nowshahr in the base period and RCP 2.6 and RCP 8.5 scenarios, the amount of rice yield in the flood treatment. It was relatively more favourable, and in other cases, periodic irrigation treatment with an 8-day cycle showed favourable performance.

Research studies and scientific reports show that the flood irrigation method is only a management tool to control pests, provide easy access to food, and prevent water stress, not a necessity. Therefore, periodic irrigation methods can reduce water consumption and prevent the harmful effects of permanent waterlogging. A comparison between the flood irrigation method with the intermittent irrigation method with an 8-day cycle showed that the periodic irrigation method with 8 days cycle could save the amount of water consumed without causing a significant decrease in yield. In the studied area, rice cultivation uses a flood irrigation regime and keeps 3-5 cm of water on the soil during the growing season. However, since the increase in water consumption did not significantly increase the yield, the periodic irrigation method can be used. Using any adaptation strategies alone may not be useful in reducing the negative effects of climate change. Therefore, identifying the most appropriate combination of adaptation strategies (planting date, fertiliser, density, and irrigation) can significantly reduce the negative effects of climate change on rice yield in the studied area. In this regard, the results showed that the planting date treatment of 5 May with a density level of 50 plants per square meter and a fertiliser level of 195 kg per hectare with an intermittent irrigation regime (8-day cycle) are the most suitable adaptation strategy to reduce the negative effects of climate change and increase the yield of rice at all levels of the region. The results of this research can reduce the adverse effects of climate change on the rice crop, and while helping to improve the food security situation, it can also improve the socio-economic conditions of the people of the study area.

References

Ahmadi, M., Ghermez Cheshmeh, B. and Ghasemieh, H., 2017. Uncertainty analysis of the statistically downscaling precipitation and Temptation on the Qorantalar. *Water Engineering*, **10(34):** 11-24. http://doi: 20.1001.1.20086377.1396.10.34.2.2.

Arouna, A., Fatognon, I., Satio, K. and Futakuchi, K., 2021. Moving toward rice self-sufficiency in sub- Saharan Africa by 2030: Lessons learned from 10 years of the coalition for African Rice development. *World Development Perspectives*, **21(3):** 1-30. http://dx.doi.org/10.2139/ssrn.3684527

Arunrat, N., Sereenonchai, S., Chaowiwat, W. and Wang, C., 2022. Climate change impact on major crop yield and water footprint under CMIP6 climate projections in repeated drought and flood areas in Thailand. *Science of the Total Environment*, **807(2):** 150-741. https://doi.org/10.1016/j.scitotenv.2021.150741

Ashouri, M. and Roudsari, L., 2019. The effect of plant density and nitrogen fertilizer levels on yield and yield component and some physiological indices of rice cv. Tarom Hashemi in Roudsar. *Applied Field Crops Research*, **32(1):** 81-100. https://doi: 10.22092/aj.2018.120278.1242.

Babazadeh, H., EbrahimiRad, H., Amiri, E. and Sedghi, H., 2018. Effect of different planting densities and irrigation managements on rice (Tarom Hashemi Variety) yield and yield components in Koosha lLahijan Region, Guilan Province. *Iranian Journal of Soil and Water Research*, **49(2):** 377-383. https://doi: 10.22059/ijswr.2017.232587.667676.

Chun, J.A., Li, S., Wang, Q., Lee, W.S., Lee, E.J., Horstmann, N., Park, H.,Veasna, T.,Vanndy, L., Pros, K. and Vang, S., 2016. Assessing rice productivity and adaptation strategies for Southeast Asia under climate change through multi-scale crop modeling. *Agricultural Systems*, **143(14):** 14-21. https://doi.org/10.1016/j.agsy.2015.12.001

Darzi Naftchali, A. and Karandish, F., 2016. Rice cultivation management in Mazandaran Province under climate change. *Journal of Water Research in Agriculture.* **30(3):** 333-346. https://doi: 10.22092/jwra.2016.107154.

Dastranj, A., Shahbazi, A., Mohsenisaravi, M., Salehnasab, A. and Jafari, S., 2016. Climate modeling and comparison of changes in climatic parameters using SDSM in the northern and southern sides of the Alborz. *Iranian Journal of Water/Fied Management Science.***10** (32), 11-26. https://doi: 20.1001.1.20089554.1395.10.32.1.8.

Esfahani, M., Adeli Mosabbab, F., Abdollahi Mobarhan, S. and Aalami, A., 2016. Effect of plant density of dry matter remobilization and grain yield for two local rice cultivars. *Cereal Research,* **5(4):** 301-310.https://doi: 20.1001.1.22520163.1394.5.4.1.8.

Esfahani, M., Nadimi Dafrazi, M. and Aalami, A., 2018. Effect of transplanting time on grain yield, yield components and remobilization of three rice (*Oryza sativa* L.) varieties in Roudbar region. *Cereal Research*, **7(4):** 471-483. https://doi: 10.22124/c.2018.3052.

Fakheran, S., Malakoutikhah, SH., Hemami, M., Tarkesh, M. and Senn, J., 2018. Altitudinal heterogeneity and vulnerability assessment of protected area network for climate change adaption planning in central Iran. *Applied Geography*, **92(143):** 94-103. https://doi.org/10.1016/j.apgeog.2018.02.006

Jing, Z., Jian, W., Zhang, G., Li, X., Shu-qing, H., Chen, SH. and Fan, K., 2021. Impact of climate change on maize yield in China from 1979 to 2016. *Journal of Integrative Agriculture*, **20(1):** 289- 299. https://doi.org/10.1016/S2095-3119(20)63244-0

Kamkar, B., Aalaee Bazkiaei, P., Amiri, E., Kazemi, H. and Rezaei, M., 2019. Effect of planting date and irrigation intervals on yield and yield components of rice (*Oryza sativa* L.) in Rasht Region. *Journal of Water Research in Agriculture*, **33(2):** 283-297. https://doi: 10.22092/jwra.2019.119743.

Karami, E., Karimi, V. and Keshavarz, M., 2019. Climate change and agriculture: Impacts and adaptive responses in Iran. *Journal of Integrative Agriculture*, **17(1):** 1-15. https://doi.org/10.1016/S2095-3119(17)61794-5

Kheyri, N., Yazdani, A., Mobser, H. and Niknejad, Y., 2015. Effect of planting pattern, split application of nitrogen fertilizer on qualitative traits, and grain yield of rice (*Oryza sativa* L.) var. Koohsar in second cropping. *Applied Research of Plant Ecophysiology*, **2(1):** 121-134.

Khorshiddoust,A., Sarraf, B., Ghermez Cheshmeh, B. and Jafarzadeh, F., 2017. Estimation and analysis of Caspian region’s future rainfalls by using general atmospheric circulation models. *Scientific Journals Management System*, **17(47):** 213-226. https://doi: 20.1001.1.22287736.1396.17.47.5.7.

Liu, Y., Zhang, X., Liu, Y., Cui, Q., Yang, L., Hu, X., Guo, J., Zhang, J. and Yang, S., 2019. Impacts of climate change on self-sufficiency of rice in China: CGE-model-based evidence with alternative regional feedback mechanisms. *Journal of Cleaner Production*, **230(959):** 150-161. https://doi.org/10.1016/j.jclepro.2019.05.075

Mall, R.K., Gupta, A. and Sonkar, G., 2017. Effect of climate change on agricultural crops. *Current Developments in Biotechnology and Bioengineering*, **10(3):** 23-46. https://doi.org/10.1016/B978-0-444-63661-4.00002-5

Mishra, A., Singh, R., Raghuwanshi, N., Chatterjee, C. and Froebrich, J., 2013. Spatial variability of climate impacts on yield of rice and wheat in the Indian Ganga Basin. *Science of Total Environment*, **468-469(48):** 5132-5138. https://doi.org/10.1016/j.scitotenv.2013.05.080

Mishra, S., Panda, D. and Behera, P., 2021. Drought tolerance in rice: focus on recent mechanisms and approaches. *Rice Science*, **28(2):** 119-132. https://doi.org/10.1016/j.rsci.2021.01.002

Moradpour, S., Amiri, E., Mobasser, H.R. and Madani, H., 2016. The effects of planting date and plant density on rice in Mazandaran province. *New Finding in Agriculture*, **9(2):** 117-127.

Nahvi, M., Alah Gholipour, M., Ghorbanpour, M. and Mehrgan, H., 2006. The effective of planting density and nitrogenous fertilizer rate for GRH1 rice Hybrid. *Pajouhesh Va Sazandgi*, **66(4):** 33-38.

Ojo, T. and Baiyegunhi, H., 2020. Impact of climate change adaption strategies on rice productivity in South-West, Nigeria: An endogeneity corrected stochastic frontier model. *Science of the Total Environment*, **745(25):** 141-151. https://doi.org/10.1016/j.scitotenv.2020.141151

Shariatmadari, Z. and Kamali, S., 2018. Evaluation of the effects of atmospheric pollutants on the performance of Angestrom-Prescott equation in estimating solar radiation (Case Study: Karaj). *Iranian Journal of Soil and Water Research*, **48(5):** 1053-1061. https://doi.org/10.22059/ijswr.2018.233499.667682

Sherestha, S., Chapagain, R. and Babel, M., 2017. Quantifying the impact of climate change on crop yield and water footprint of rice in the Nam Oan Irrigation Projected, Thailand. *Science of the Total Environment*, **599(1):** 600-699. https://doi.org/10.1016/j.scitotenv.2017.05.028

Surendran, U., Raja, P., Jayakumar, M. and Subramoniam, R., 2021. Use of efficient water saving techniques for production of rice in India under climate change scenario: A critical review. *Journal of Cleaner Production*, **309(1):** 127-272. https://doi.org/10.1016/j.jclepro.2021.127272

Wang, J., Guo, H., Wang, R., Garfin, G., Zhang, A., Lin, D. and Liang, Q., 2021. Rice drought risk assessment under climate change: Based on physical vulnerability a quantitative assessment method. *Science of the Total Environment*, **751(10):** 125-137. https://doi.org/10.1016/j.scitotenv.2020.141481

Zhou, G., Zhang, H., Liu, D., Wang, B., Xiao, D. and He, L., 2019. Climate-associated rice yield change in the Northeast China plain: A simulation analysis based on CMIP5 multi-model ensemble projection. *Science of the Total Environment*, **666(20):** 126-138. https://doi.org/10.1016/j.scitotenv.2019.01.415

Ziaee, S., Kalbali, E., Najafabadi, M. and Zakerinia, M., 2021. Approaches to adapting to impacts of climate change in northern Iran: The application of a hydrogy-economics model. *Journal of Cleaner Production*, **280(1):** 1-15. https://doi.org/10.1016/j.jclepro.2020.124067